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THE EFFECTS OF DIFFERENT RATES OF THE HERBICIDE GLYPHOSATE ON SPIDERS IN ARABLE FIELD MARGINS

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ABSTRACT. Field margins are susceptible to agro-chemical spray drift, and the effects of herbicide on spiders in semi-natural habitats have been little studied. In this experiment, an arable field margin was sprayed with three rates of glyphosate (90 g active ingredient/hectare (a.i/ha), 180 g a.i./ha & 360 g a.i./ha) and control plots left unsprayed. Spiders were sampled monthly (June-October) using a converted garden-vac and adult spiders were identified to species. A total of 23,393 spiders was sampled with the web-spinners representing more than 90% of the individuals. The effects of glyphosate application on the abundance of wandering and web-spinning prey-capture guilds, and the two most abundant species (*Gonatium rubens* and *Lepthyphantes tenuis*) were analyzed using ANOVA F tests. The highest rate of glyphosate consistently reduced the total number of spiders, the numbers of web-spinners, *G. rubens* and *L. tenuis,* but not numbers of wandering spiders. Changes in vegetation structure and microclimate caused by the glyphosate are implicated in the reduction of numbers of spiders in plots receiving the highest rate of glyphosate. We conclude that glyphosate drift at rates of more than 360 g a.i./ha (active ingredients per hectare) into arable field margins could result in significant losses of important arthropod predators in farmland and a reduction in spider biodiversity in agroecosystems.

In the United Kingdom, arable field margins commonly comprise a boundary (hedge, fence, wall, or ditch) and a grass-dominated boundary strip, and these constituent parts have been shown to be beneficial in enhancing flora, mammals, game birds and insects on arable farmland (e.g., Boatman 1994). Arable field margins are important as overwintering sites (Bayram & Luff 1993), permanent habitats (Alderweireldt 1994a) and refuges for recovery (Thomas et al. 1991) for spiders in the agroecosystem. Not only do arable field margins increase the opportunity for enhancing spiders as predators (Alderweireldt 1994a), but they are able to increase spider-biodiversity within biologically-impoverished arable land (Duelli et al. 1990).

Field margins are susceptible to direct herbicide applications (Boatman 1989) and also to spray drift by the virtue of their proximity to high-input cropped areas. Glyphosate is a commonly used herbicide and with the development of herbicide resistant crops, the use of non-selective herbicides like glyphosate is likely to increase (Mueller & Womac 1997). Research into the optimum width of buffer zones for reducing spray drift into sensitive areas has recommended margins in the order of 6 m wide for reduction of the most toxic effects of various pesticides (Marrs et al. 1992; de Snoo 1997).

Although the impact of insecticides on spider behavior (Samu & Vollrath 1992) and mortality (Everts et al. 1989) has been studied, the effects of herbicide contamination on spiders remain little-researched (Raatikainen & Huhta 1968; Asteraki et al. 1992). Spiders are sensitive to changes in vegetation structure, where a highly variable structure provides web-spinners with increased web-site opportunities. Availability of structural support for webs and a suitable micro-climate (ameliorated fluctuations in humidity and temperature) are the most important factors in web site selection (Samu et al. 1996). The intrinsic action of herbicide on plants alters both the vegetation structure and therefore microclimate conditions, and so it is likely that changes in spider fauna would occur when a habitat is exposed to a herbicide application. Here, we subjected an arable field margin to a herbicide application to establish whether relative spider population, prey-capture guild and number of individuals of abundant species were affected.

METHODS

Site.—A well established arable field margin was selected on the Allerton Research and Educational Trust's Loddington Estate in Leicestershire, UK. The field margin was dominated by couch grass (*Elymus repens* (L.)) and false oat grass (*Arrhenatherum elatius* (L.)) and lay adjacent to a dense uncut hawthorn (*Crataegus monogyna* Jacq.) and blackthorn (*Prunus spinosa* L.) hedge. The field margin was east-south-east facing on slightly stoney clay soils from the Hanslope Series and the field was sown to winter barley (cultivar: Fighter).

Treatments.—Eight replicates of four treatments (90 g active ingredient/hectare (a.i./ha), 180 g a.i./ha & 360 g a.i./ha glyphosate and control) were randomly applied to adjacent field margin plots, which measured 12 m × 1 m. The glyphosate (Roundup Biactive™, Monsanto) was applied to the plots at a volume rate of 200 liters/ha and a pressure of 25 bars using an Oxford Precision sprayer on 30 May 1997.

Sampling.—Spiders were sampled using a modified garden-vac (g-vac) (Ryobi RSV3100E). As a relatively new arthropod sampling device, the g-vac has received critical attention. Its sampling efficiency has been reviewed and the machine used in this experiment has been considered to be an effective method of sampling spiders (Samu et al. 1997). The g-vac samples comprised 10 sub-samples of 30 second 'sucks' at 1 m intervals along each experimental plot. This approximated to a total sampling area per plot of 0.13 m^2. The invertebrate samples were cooled immediately and then extracted with an aspirator into 70% alcohol before being identified. All adult spiders were identified to species, whilst immatures were included in total number of spiders.

Spiders were sampled prior to the herbicide application to confirm that plots did not support different abundances of spiders. Spiders were then sampled two weeks post-herbicide application and monthly thereafter. Spiders were sampled from June to October inclusive.

Statistical analysis.—Total spider abundance data and prey-capturing guild data were $\log(x + 1)$ transformed while spider species abundance data were square-root $(x + 0.5)$ transformed. Two-way univariate repeated measures ANOVAs were used to test for differences in mean number of spiders between treatments because the samples of spiders through the season could not be considered to be independent of each other (Von Ende 1993). Where an interaction between treatment and date existed, indicating that the effect of treatment differed between dates, a one-way univariate ANOVA was used to test for differences in mean number of spiders between treatments in each month. Planned comparisons were used to test for differences implicit in the experimental design: we used Least Significant Difference (LSD) tests to determine differences between means (Sokal & Rohlf 1995).

RESULTS

A total of 23,393 spiders from 11 families and 67 species was recorded and the dominant family was the Linyphiidae. Specimens have been deposited at the Liverpool Museum, UK.

Pre-treatment.—Spider abundance did not differ between plots prior to treatment application (ANOVA $F_{(3, 28)} = 1.31$; $P = 0.2901$). We therefore considered the plots to be similar in spider fauna composition and proceeded with analysis.

Total spider abundance.—Two-way repeated measures ANOVA indicated that there was a significant date × treatment interaction ($F_{(15, 140)} = 2.69$; $P < 0.0013$), so we analyzed data from individual months. Total abundance of spiders was only significantly different between treatments in September (one-way ANOVA $F_{(3, 28)} = 4.01$; $P < 0.0171$), where significantly fewer spiders were found in the 360 g a.i./ha treatment than in all other treatments (Table 1).

Prey-capture guilds.—Web-spinning adult spiders from the Tetragnathidae, Theridiidae and Linyphiidae and wandering adult spiders from the Thomisidae, Clubionidae, Pisauridae, Zoridae, Oonopidae and Lycosidae were grouped to investigate the treatment effects on these two prey-capture guilds. Table 2 shows the mean number of individuals from the families in the two guilds in each of the treatments. Web-spinning spiders were dominated

Table 1.—Mean total number of spiders in treatments and LSD P values for differences between means in all treatments and 360 g active ingredient/hectare (a.i./ha).

	Control	90 g a.i./ha	180 g a.i./ha	360 g a.i./ha
mean	220.50	205.13	209.38	152.13
P	<0.0037	<0.0174	<0.0136	—

by the Linyphiidae and were more abundant than wandering spiders, where they represented more than 90% of individuals in these two guilds. Wandering spiders were not found to differ between treatments (repeated measures ANOVA $F_{(3, 28)} = 0.67$; $P < 0.5779$).

Two-way repeated measures ANOVA indicated that there was a significant treatment by date interaction ($F_{(12, 112)} = 2.61$; $P < 0.0042$) for web-spinners, so we analyzed data from individual months. The number of web-spinners was significantly different among treatments in August, September and October, where more spiders were found in the control plots than in the 360 g a.i./ha in September and October only (Table 3).

Species data.—Only species which occurred in sufficient numbers (mean number individuals > 1.5 in each month) were analyzed individually. Only two linyphiid species fulfilled this criterion and showed significantly different mean abundances among treatments.

Gonatium rubens (Blackwall 1833) showed different abundances in different treatments (repeated measures ANOVA $F_{(3, 28)} = 4.41$; $P < 0.0116$) in months August to October, where the control and 90 g a.i./ha plots had significantly more individuals (LSD $P < 0.0043$; LSD $P < 0.0072$ for control and 90 g a.i./ha respectively) than the 360 g a.i./ha treatment.

Lepthyphantes tenuis (Blackwall 1852) showed different abundances in different treatments in September and October (repeated measures ANOVA $F_{(3, 28)} = 7.63$; $P < 0.0007$), where each of the other treatments had significantly more individuals than the 360 g a.i./ha treatment (Table 4).

Table 2.—Mean number of individuals in each family from treatments (June to October). a.i./ha = active ingredient/hectare.

	Control	90 g a.i./ha	180 g a.i./ha	360 g a.i./ha
Wandering spiders				
Thomisidae	—	—	0.4	0.3
Clubionidae	0.4	0.4	0.3	0.4
Pisauridae	—	0.3	—	—
Zoridae	—	0.1	0.1	0.1
Oonopidae	—	—	0.1	—
Lycosidae	2.6	2.4	1.8	4.3
Web spinners				
Tetragnathidae	0.8	0.6	0.8	1.3
Theridiidae	6.8	6.3	10.9	7.3
Linyphiidae	29.2	27.3	32.7	24.1

DISCUSSION

General effect of treatment.—Applications of glyphosate at 360 g a.i./ha significantly reduced the abundance of total spiders, web-spinners, *Gonatium rubens* and *Lepthyphantes tenuis,* but not of wandering spiders. The lower rates of herbicide had little or no effect on the abundance of spiders per se; however, this study does not take into effect possible changes in wandering and mating.

The initial effects of the herbicide on the total number of spiders and prey-capture guilds were insignificant, but became more profound as the season progressed. Therefore, it is assumed that spiders are not affected directly by glyphosate (which is generally non-toxic to animals), but indirectly by modifications of other factors, such as habitat, prey availability and microclimatic conditions. The time taken for the herbicide to act on vegetation and change the habitat sufficiently for spiders to exert preferences clearly takes months rather than weeks. Where such effects are widespread, numbers of spiders may be low in the following spring, which is a time when spiders are a determining factor in aphid population dynamics in wheat crops (Cocquempot & Chambon 1990). Thus, our single season study indicates that the longer term effects of herbicide on spiders as biocontrol agents and spider species diversity in agroecosystems are of concern.

Wandering spiders.—The highest rate of herbicide did not significantly reduce the

Table 3.—Comparison of mean number of web-spinners between different treatments & LSD *P* values for differences between means in all treatments and 360 g active ingredient/hectare (a.i./ha).

	August		September		October	
Treatment	mean	*P*	mean	*P*	mean	*P*
control	10.00	ns	28.0	<0.0007	85.25	<0.0061
90 g a.i./ha	8.25	ns	24.75	<0.0059	82.13	<0.0159
180 g a.i./ha	19.25	<0.0226	29.86	<0.0004	82.50	<0.0230
360 g a.i./ha	7.25	—	16.38	—	66.50	—

number of wandering spiders. Wandering spiders generally contain few examples of stenophages (Nentwig 1986) and they may be more adept at finding suitable food items in disturbed habitats due to their prey-capture strategy (Young & Edwards 1990). Thus, a combination of feeding strategy and an available diverse prey source may not have sufficiently deterred the wandering spiders from using the herbicide treated plots.

Vegetation structure can influence not only wandering spider prey recognition (Rovner 1980) but also mate detection (Uetz & Stratton 1982). The indirect effects of herbicide on the ability of spiders to detect mates was not recorded, and we suggest that long-term experiments should concentrate on mating success and feeding ability to investigate any correlations with herbicide use.

Web-spinners.—The action of herbicide on vegetation results in sparse cover and reduced vegetation height (Raatikainen & Huhta 1968) as plants lose their vigor. Web-spinning spiders rely on vegetation structure to provide both web-attachment sites and appropriate humidity (Greenstone 1984; Young & Edwards 1990; White & Hassall 1994). Unlike wandering spiders, web-spinning linyphiids tend to have preferences for specific prey type (Alderweireldt 1994b). Many web-spinning spiders, therefore, may not utilize sub-standard habitat with a poor prey availability, since they invest energy in web-building (Uetz 1991). The web-spinners in this study represented the dominant prey-capture guild and indicated that higher levels of herbicide resulted in unfavorable habitat. Such losses of important farmland spiders from herbicide misapplications could be significant in terms of conservation of spiders in agroecosystems and in enhancing spiders as predators.

Table 4.—Comparison of mean number of *Lepthyphantes tenuis* between different treatments & LSD *P* values for differences between means in all treatments and 360 g active ingredient/hectare (a.i./ha).

	September & October	
Treatment	mean	*P*
control	34.38	<0.0002
90 g a.i./ha	34.19	<0.0005
180 g a.i./ha	31.75	<0.0072
360 g a.i./ha	24.38	—

Gonatium rubens: This linyphiid is a litter species (McFerran et al. 1994) and it showed a preference away from heavily sprayed plots. Although autecological literature about G. rubens is sparse, as a web-spinning spider it has similar habitat requirements as those outlined above. It must be concluded that all, or a combination of, abundance of web-building sites, availability of prey and level of humidity were sub-standard.

Lepthyphantes tenuis: The most abundant spider in the British agroecosystem is *L. tenuis* (Topping & Lovei 1997). This linyphiid builds webs at 10 cm above the ground and is completely dependent upon web-building for prey (Alderweireldt 1994b). As vegetation height is reduced under exposure to herbicide (Raatikainen & Huhta 1968), the ideal web-building height for *L. tenuis* may become displaced to a height with reduced humidity. Aphids form a large part of the diet of *L. tenuis* (Alderweireldt 1994b) and the spider can reduce the aphid (*Rhopalosiphum padi* L.) population on wheat plants by 34% (Mansour & Heimbach 1993). Thus, *Lepthyphantes tenuis* is an important predator in farmland and reductions caused by herbicide applications should be considered against the benefits of biocontrol.

Conclusions.—Herbicide applications at higher rates reduce the abundance of important predators. Field margins, which are valued as refuges for farmland spiders during winter and periods of disturbance, are susceptible to herbicide spray drift and may suffer losses in spider fauna. Reduced herbicide use in and near field margins is suggested here and elsewhere (Young & Edwards 1990) as a way of enhancing spider populations in agroecosystems not only for biocontrol but also for conservation of spider biodiversity.

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